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(54) **ANTI-FOULING ROBOT**

(57) The invention proposes an anti-fouling robot (14), for cleaning a hull (12) of a marine vessel (10), comprising an attachment device (18) configured to adhere the robot (14) to the hull (12) of the marine vessel (10), a maneuvering device (22) configured to move the robot (14) across the surface of the hull (12) of the marine ves-

sel (10), a cleaning device (20) configured to remove biofouling from the surface of the hull (12) of the marine vessel (10), and an energy generation device (24) configured to generate energy for the operation of the robot (14).

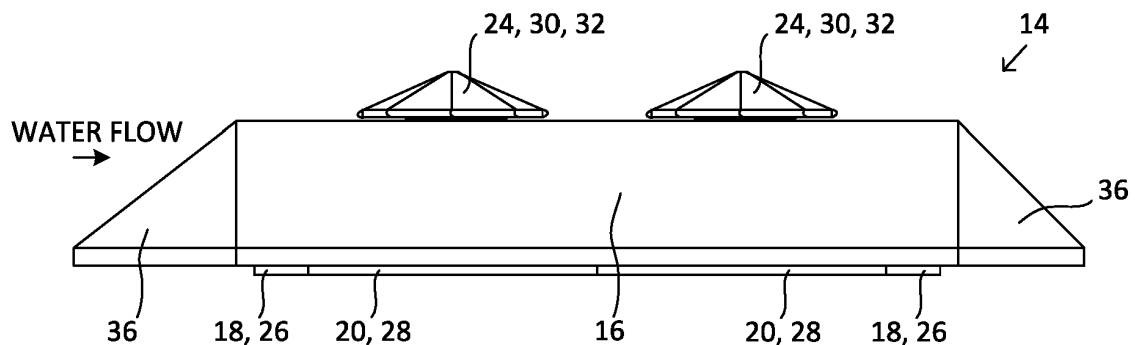


Fig.3

EP 3 838 736 A1

Description

[0001] The invention relates to an anti-fouling robot for cleaning a hull of a marine vessel.

[0002] The hull of a marine vessel is partially submerged in water wherein the submerged surfaces are subject to biofouling. In an early stage of biofouling, the surface is covered with a coat of organic polymers on which microbes such as bacteria and diatoms can adhere and form a biofilm. On the biofilm, larger algae and animals can attach and grow. Biofouling significantly increases the drag, reduces the hydrodynamic performance of the vessel and in particular increases fuel consumption of motorized marine vessels.

[0003] EP 3 415 412 A1 for example discloses a remote controlled underwater vehicle that carries a cleaning apparatus for cleaning the hull of a ship.

[0004] It is an object of this invention to provide an anti-fouling robot which can function autonomously to clean the hull of a marine vessel.

[0005] The invention proposes an anti-fouling robot which the features of claim 1. Further advantageous embodiments are disclosed in the dependent claims.

[0006] An anti-fouling robot for cleaning a hull of a marine vessel according to the invention comprises an attachment device configured to adhere the robot to the hull of the marine vessel, a maneuvering device configured to move the robot across the surface of the hull of the marine vessel, a cleaning device configured to remove biofouling from the surface of the hull of the marine vessel, and an energy generation device configured to generate energy for the operation of the robot. This enables the robot to function autonomously which in particular enables the robot to clean the hull of the marine vessel continuously during operation of the marine vessel.

[0007] The energy generation device preferably comprises at least one electric generator which generates electricity from the movement of the marine vessel through the water. This enables a sustainable and simple energy generation, in particular while the marine vessel is traveling or from the movement of waves across the robot.

[0008] The electric generator may be omni-directional which enables the generator to generate electricity independently of the orientation of the robot relative to the movement of water over the robot.

[0009] The electric generator may have a turbine rotor which comprises adaptive blades which are configured to adapt to the direction of the water flow; preferably wherein the adaptive blades are configured to unfold when facing the flow direction and fold when facing away from the flow direction; further preferably wherein the unfolding of the adaptive blades is actuated by water flowing into vanes which are situated on the turbine rotor in rotational direction ahead of the corresponding adaptive blade. This enables a simple geometry of the turbine rotor that is adaptable to the direction of the movement of water

over the robot. Further, each vane can capture the on-coming flow of water and use it to apply a raising force to unfold its following adaptive blade.

[0010] The electric generator further may comprise a central shaft and a coupling which allows coupling and decoupling of the turbine rotor to the central shaft. This allows decoupling of the turbine rotor from the central shaft when the robot operates out of the water or when there is insufficient water flow for energy generation.

[0011] The energy generation device may further include a battery which can be charged with the generated energy. The energy stored in the battery may be used to operate the robot in conditions in which insufficient energy can be created, e.g. because the marine vessel is not moving.

[0012] The attachment device may comprise at least one permanent magnet or at least one suction unit, preferably at least two permanent magnets or suction units. The permanent magnet enables the robot to stay attached to e.g. a ferromagnetic hull of the marine vessel independently of a power supply. Suction units allow the robot to also adhere on other hulls such as wooden or plastic hulls.

[0013] The attachment device may further comprise additional attachment units which can be activated and deactivated based on a desired attachment force. This enables the robot to secure itself to the hull of the marine vessel even during difficult conditions, e.g. during a storm.

[0014] The attachment device may further comprise a detachment unit which can be activated to counteract an attachment force, in particular the attachment force of a permanent magnet. The detachment unit preferably is an electromagnet which can generate a magnetic field to cancel out the field of the permanent magnet. The detachment unit may be one of the additional attachment units which is configured to be operable to generate both an attachment force and a detachment force. Alternatively the detachment unit can be independent of other robot systems and can only be activated externally, e.g. by activating an electromagnet or a different detachment unit by induction, in order to avoid accidental detachment because of a malfunction of the robot systems.

[0015] The maneuvering device may comprise one or more feet, wheels and/or continuous track maneuvering devices.

[0016] Alternatively, the maneuvering device may comprise at least two attachment units configured to alternately adhere the robot to the hull of the marine vessel at off-center locations of the robot body and a rotation device configured to rotate the robot around the off-center locations of the at least two attachment units. This enables a maneuvering method for the robot in which the robot is attached to the hull at a first off-center location of the robot body by a first attachment unit and is rotated by the rotation device around the first off-center location of the robot body, preferably wherein the rotation is actuated by a mechanical force of the flow of water acting

upon the robot body. After rotation of a certain angle, the robot adheres to the hull at the second off-center location with the second attachment unit and consequently releases the first attachment unit to allow rotation of the robot around the second off-center location. The robot may therefore take steps which correspond to the distance between the two off-center locations wherein the angle of the rotation determines the direction of the step.

[0017] The cleaning device may comprise at least one rotating cleaning disc which enables a mechanical removal of biofouling from the hull surface.

[0018] The rotating cleaning disc may comprise a turbine rotor connected to the cleaning disc, wherein the turbine rotor comprises adaptive blades configured to adapt to the direction of the water flow, preferably wherein the adaptive blades are configured to unfold when facing the flow direction and to fold when facing away from the flow direction; further preferably wherein the unfolding is actuated by water flowing into vanes which are situated on the turbine rotor in rotational direction ahead of the corresponding adaptive blade. In this manner, the cleaning disc is rotated at least partially by the force of the water flow and the robot requires less energy compared e.g. to purely electrically powered cleaning discs.

[0019] The cleaning device may comprise a UV light source, a laser or ultrasound source and/or high pressure jet nozzles. In this manner, different methods for removing and neutralizing biofouling can be used either alternatively or in combination.

[0020] The cleaning device may comprise radial arms which bias a cleaning unit against the surface of the hull and which move in circumferential direction, wherein the radial arms preferably have a plurality of articulated segments. In this manner, the robot can clean a relatively large area of the hull while having a relatively low weight.

[0021] For improved autonomy, the robot further may further have a control device which has at least one of the following: a sensor for determining the locations of the robot on the hull, wherein the control device preferably controls the robot to move the robot to a safe location on the hull when the marine vessel enters a harbor; a sensor for determining the geographic location of the marine vessel, wherein the control device preferably controls the robot to stop or start a cleaning operation depending on the geographic location; a sensor for determining a degree of biofouling on the hull, wherein the control device preferably controls the robot maneuvering speed, path and/or a cleaning device mode based on the determined degree of biofouling; a sensor for determining an operating state of the robot, in particular a degradation of the cleaning device, wherein the control device preferably controls the robot based on the determined operating state of the robot; a sensor for determining the direction of a water flow. This improves the autonomous function of the robot so that the crew of the marine vessel preferably needs to interact with the robot as little as possible and preferably do not have to take the robot into consideration while operating the marine vessel.

[0022] Advantageously, the control device comprises a communication system which allows the robot to communicate with an external service center. This preferably enables the robot to function completely independent of the crew of the marine vessel. The robot may for example report its operating state to the service center which can schedule an inspection of the robot at a suitable time, e.g. the next time the marine vessel is in a suitable port. The communication system may be a satellite communication system or can be a mobile phone system or other wireless communication system which can be used e.g. when the ship is in port and in local range of the wireless communication system. Communication system may include a satellite data link, in particular to be used intermittently when the robot is at or above the waterline; GSM mobile communication system, Bluetooth or Wifi, in particular when in range and the robot is at or above the waterline; and/or acoustic modem, in particular when the marine vessel is in harbor and the marine vessel is stopped.

[0023] The robot may have at least one coupling device configured to couple two or more robots together, wherein two or more coupled robots are configured to be controlled cooperatively. This modular design allows simple adjustments to the size of the hull or the cleaning time of the hull as additional robots can be deployed to clean a larger hull in the same time or to clean a hull in a shorter time.

[0024] Preferably, the robot is configured to orientate itself on the hull to minimize its cross section in flow direction of the water flow. This may reduce the force of the water flow across acting on the robot and may minimize the drag by the robot attached to the hull.

[0025] The robot may further include a buoyancy device which is configured to provide the robot with neutral buoyancy. Further, the buoyancy device may be configured to adjust the buoyancy of the robot and may in particular be configured to increase the buoyancy in case in which the robot detaches from the hull of the marine vessel to allow simple recovery of the detached robot. Alternatively, the buoyancy device can be configured to make the robot sink by decreasing buoyancy in a case in which it detaches from the hull of the marine vessel in order to avoid the risk of collisions. The robot may be equipped with a distress beacon which allows the robot to be located and retrieved, in particular in shallow waters.

[0026] The attachment device and/or the maneuvering device may further include a spacer device which maintains a predetermined gap between the body of the robot and the hull. The spacer device may further be configured to adapt the predetermined gap based on operating conditions, e.g. the gap may be reduced if the robot is not in cleaning operation or if an increased attachment force is required e.g. during storm conditions.

[0027] The robot may be coated with a hydrophobic coating. In this manner, the drag induced by the robot on the moving vessel may be reduced and biofouling on the robot itself may be reduced.

[0028] The robot may have an external control unit in particular at a above water location on the marine vessel, wherein the external control unit is wirelessly linked with the control device of the robot and which may be configured to contain sensors such a geographic location sensor, to notify the crew of the marine vessel or an external service provider of the operating conditions of the robot, e.g. a need for replacement of a cleaning device component, and/or to allow manual control of the robot, e.g. to cause the robot to move to a predetermined location on the hull, e.g. for inspection of the robot.

[0029] The control device may be configured to generate a path for the robot on the hull based on predetermined parameters, e.g. the size and shape of the hull of the marine vessel, or to generate a random path for the robot.

[0030] Further features and advantages of the invention are disclosed in the following description and in the figures on which it is based:

Figure 1 shows a marine vessel with an anti-fouling robot according to the invention;

Figure 2 shows an anti-fouling robot according to a first embodiment of the invention attached to a hull of a marine vessel in a side view;

Figure 3 shows the anti-fouling robot of Figure 2 in a front view;

Figure 4 shows the anti-fouling robot of Figure 2 in a top view;

Figure 5 shows the anti-fouling robot of Figure 2 in a bottom view;

Figure 6 shows a group of coupled anti-fouling robots of Figure 2 attached to the hull of the marine vessel;

Figure 7 shows a side view of two coupled robots of Figure 2;

Figure 8 shows a front view of two coupled robots of Figure 2;

Figure 9 shows a schematic overview of an energy generation device;

Figure 10 shows a top view of a turbine rotor of the energy generation device of Figure 9;

Figure 11 shows an anti-fouling robot according to a second embodiment of the invention attached to a hull of a marine vessel in a side view;

Figure 12 shows the anti-fouling robot of Figure 11 in a front view;

Figure 13 shows the anti-fouling robot of Figure 11 in a top view;

Figure 14 shows the anti-fouling robot of Figure 11 in a bottom view;

Figure 15 shows a top view of two coupled anti-fouling robots of Figure 11;

Figure 16 shows a schematic view of a cleaning device of the robot of Figure 11;

Figure 17 shows an anti-fouling robot according to a third embodiment of the invention in a top view;

Figure 18 shows the central portion of the robot of Figure 17 in a bottom view;

Figure 19 shows the central portion and one arm of the robot of Figure 17 in a side view;

Figure 20 shows a central portion and the arm of the robot of Figure 19 in a front view;

Figure 21 shows a top view of the segments of the arm of Figure 20;

Figure 22 shows detailed side views of the arm segments of the arm of Figure 21;

Figure 23 shows a front view of an articulated robot arm in different configurations;

Figure 24 shows schematic illustrations of the cleaning device of the robot of Figure 17;

Figure 25 shows a detailed illustration of a cleaning strip segment in front view;

Figure 26 shows the cleaning strip segment of figure 25 in a top view; and

Figure 27 shows the cleaning strip segment of figure 25 in a section view.

[0031] Figure 1 shows a marine vessel 10 with a hull 12 which is partially submerged in water. On the surface of the submerged portion of the hull 12 biofouling will generally occur which gradually will increase the drag of the marine vessel 10 and therefore decrease the fuel efficiency of the marine vessel 10. An anti-fouling robot 14 is provided on the hull 12 of the marine vessel 10 which is configured to clean the hull 12 autonomously and continuously and thereby remove/reduce the biofouling. In this manner, the negative effects of the biofouling can be avoided and the fuel efficiency of the marine vessel 10 can be increased. A cleaning cycle in which the robot cleans the entire hull 12 is preferably 4 weeks or less and further preferably 1 week or less. This allows the removal of the biofouling in the microbial biofilm stage and prevents biofouling by larger algae and animals.

[0032] If a robot 14 is newly deployed on a hull 12 with a high degree of biofouling with large algae and animals such as barnacles, the first cleaning cycle or cycles may be done with a first type of cleaning device which is more aggressive and abrasive. For following cleaning cycles, the cleaning device can then be replaced with a less aggressive cleaning device to protect the paint coat of the hull 12, e.g. during a scheduled inspection at a suitable port.

[0033] A first embodiment of the anti-fouling robot 14 is shown in Fig. 2 to 8, wherein Fig. 2 shows a side view of the robot 14 attached to the hull 12, Fig. 3 shows a front view of the robot seen from the direction in which the robot 14 is generally configured to move during cleaning operation, Fig. 4 shows a top view and Fig. 5 a bottom view of the robot 14.

[0034] The robot 14 comprises a main housing 16 which houses an attachment device 18 configured to adhere the robot 14 to the hull 12, a cleaning device 20, configured to remove biofouling from the surface of the hull 12 of the marine vessel 10, a maneuvering device 22 configured to move the robot 14 across the surface of the hull 12 of the marine vessel 10, and an energy

generation device 24 configured to generate energy for the operation of the robot 14.

[0035] In the first embodiment the attachment device 18 comprises four permanent magnets 26 which are arranged at the four corners of the main housing 16 and which enable the robot 14 to stay attached to the hull 12 of the marine vessel 10 independently of any energy supply.

[0036] The attachment device 18 may further include additional attachment units which can be activated and deactivated based on a desired attachment force. For example, a stronger attachment force may be desirable when the marine vessel 10 travels at greater speeds or during rough conditions, such as during a storm. Such conditions can either be determined by the robot 14 itself, for example by sensors which measure the speed and direction a water flow across the body of the robot 14. Alternatively they may be set externally by a user or automatic system, which may for example determine weather conditions from a weather forecast.

[0037] The additional attachment units can for example be electromagnets or suction cups. Depending on the desired attachment force and the type of attachment units the cleaning operation of the robot 14 may be stopped so that the robot 14 remains immobile on the hull 12 of the marine vessel 10 during the time in which the increased attachment force is required. It is also possible to control the robot 14 to move to a predetermined location on the hull 12 of the marine vessel 10, at which the forces acting on the robot 14 are lower, for example during rough conditions during a storm.

[0038] In the preferred embodiment, the additional attachment units further serves as a detachment unit which can be activated to counteract the attachment force of the permanent magnets 26. The additional attachment/detachment unit of the preferred embodiment is an electromagnet which can generate a magnetic field to generate either an attachment force or a detachment force.

[0039] Alternatively, a detachment unit is provided independently of other robot systems and can only be activated externally, e.g. by activating the electromagnet by induction, in order to avoid accidental detachment e.g. due to a malfunction of the robot systems.

[0040] It is preferably also possible to adjust a gap between the main body 16 of the robot 14 and the hull 12 of the marine vessel 10, e.g. by adjusting the height of feet or wheels which contact the hull 12. The gap may be increased to allow the robot to overcome minor obstacles on the hulls or for movement on a curved portion of the hull.

[0041] The main housing 16 may also have a sealing lip along the outer edge of the bottom surface of the main housing 16, so that the essentially entire main housing 16 may act as a suction cup if the sealing lip contacts the hull 12 of the marine vessel 10. This suction cup function may be activated by decreasing the gap between the main body 16 and the hull 12 and driving a pump to pump

out water from underneath the bottom surface of the main housing 16.

[0042] The main body 16 may further house a buoyancy device so that the robot 14 preferably has neutral buoyancy in the water. It is also possible that the buoyancy device is able to adjust the buoyancy of the robot 14. For example, the buoyancy of the robot can be increased if the robot 14 is accidentally detached from the hull 12 of the marine vessel 10. In such a case, the detached robot 14 may be more easily recovered. Alternatively, the buoyancy device can decrease the buoyancy to allow the robot to sink to a depth in which collisions with other vessels can be avoided. A distress beacon may be provided to allow the robot to be more easily located.

[0043] In the first embodiment, the cleaning device 20 comprises two rotating cleaning disks 28 situated on the bottom side of the main body 16. In the present embodiment the rotating disks 28 are powered by an electric motor housed inside the main housing 16 of the robot 14. The rotating cleaning disks 28 may alternatively be driven by an oscillating motor, a hydraulic motor or by a mechanical connection to the energy generation device 24, e.g. via a gearbox. The rotating cleaning disks 28 allow cleaning of the hull 12 independently of a movement of the robot 14.

[0044] The cleaning disks 28 may be configured for scouring, brushing, wiping, grinding, cutting or sponging the surface of the hull 12. The two rotating cleaning disks 28 may be of the same type or may be of different types to allow a different cleaning method respectively.

[0045] The rotating cleaning disks 28 can be driven independently of each other or alternatively can be mechanically connected to each other via gearing or coupling, in particular so that they can rotate in unison, albeit in opposite directions. Such mechanically connected cleaning discs 28 may also have an interlocking shape, e.g. a cogwheel shape, along their circumference in order to allow them to overlap in the moving direction of the robot 14.

[0046] The cleaning device 20 has a mechanism for generating a downwards force which biases the cleaning disks 28 against the hull 12 of the marine vessel 10. The mechanism may have the ability to increase or decrease the downwards force that biases the cleaning disks 28 against the hull 12, for example depending on the degree of biofouling and/or wear of the cleaning disks 28.

[0047] The cleaning device 20 may further comprise a UV light source, a laser or ultrasound source, and/or high-pressure jet nozzles in order to allow additional, alternative, or synergetic cleaning methods.

[0048] The maneuvering device 22 may comprise one or more feet, wheels, and/or continuous track-maneuvering devices. It is also possible that the maneuvering device 22 and the attachment device 18 are combined, for example permanent magnets 26 can be integrated into individual feet or a continuous track-maneuvering device.

[0049] The energy generation device 24 of the first em-

bodiment shown in figures 2 to 5 comprises two omnidirectional electric generators 30, which comprise a turbine rotor 32 situated on top of the main housing 16. The omnidirectional electric generator 30 is configured to generate electricity from the movement of the marine vessel 10 in the water. When the marine vessel 10 is travelling, water flows along the outside of the hull 12 and along the robot 14 attached thereon. This water flow is able to turn the turbine rotor 32 of the omnidirectional electric generator 30 independently of the orientation of the robot 14 on the hull 12. Electricity may also be generated when the marine vessel 10 is not travelling by the movement of water relative to the robot 14 attached on the hull of the marine vessel, e.g. by waves or tidal effects.

[0050] As can be seen in figures 4 and 5, the main housing 16 of the robot 14 has a low-profile rectangular body, whose width is a multiple of its length. The short length and low profile allow the robot to have a relatively small cross section in direction of the water flow when the marine vessel 10 is moving and therefore only minimally increases the drag of the marine vessel 10.

[0051] On the relatively short side surfaces of the main housing 16 the robot 14 has coupling devices 34, which are configured to couple two or more robots 14 together, such that the two or more coupled robots can be controlled cooperatively. In the present embodiment, if one or both of the coupling devices 34 are not coupled to another robot 14, they are covered by a fairing 36 that reduces drag and acts to provide a local downwards force towards the hull 12 of the marine vessel 10.

[0052] During operation of the robot 14, the robot orientates itself on the hull 12 in a direction so that the profile facing the water flow direction is minimized. Preferably, the robot 14 moves in a direction perpendicular to the water flow during the cleaning operation. The water flow is indicated with the arrow in figure 3 and the forward direction of the robot movement during cleaning operation is indicated by the arrow in figure 4. The robot 14 orientates itself on the hull 12 to minimize its cross-section into the oncoming flow direction of the water flow.

[0053] Figure 6 shows a group of three robots 14, which are coupled together by the coupling devices 34. The two robots 14 at either end of the robot group have fairings 36, which cover the corresponding uncoupled coupling devices 34. Figure 6 shows the coupling devices 34 between the individual robot units in an open state. However, it is also possible that the coupling devices 34 are likewise covered by a fairing situated between the individual robot units in order to optimize the hydro-dynamic profile of the group of robots.

[0054] As can be seen in figures 7 and 8 the coupling devices 34 of the present embodiment function like a ball & socket coupling, which allows a high degree of relative movement of the neighboring robot units. This allows even a larger group of coupled robots to closely follow the profile of the hull 12 of the vessel 10, as shown in figure 6. Figure 7 shows two different robot units, which are rotated relative to each other around a roll axis of the

robot group (seen in the direction of the hydrodynamic water flow).

[0055] Figure 8 shows two coupled robot units, which are rotated relative to each other around their pitch axis. Similarly, rotation may also be possible around the third axis, which is around the yaw angle.

[0056] The coupling devices can be configured to be operated manually so that robots are coupled when they are installed on the hull or during an inspection. Alternatively, the robots may be configured to automatically couple and decouple and may be configured to clean some sections of the hull cooperatively in coupled state and other sections of the hull as individual robots or as smaller groups of robots.

[0057] Figure 9 shows a schematic view of the omnidirectional electric generator 30. The turbine rotor 32 is connected to a central shaft 38, which allows transmission of a rotation from the turbine rotor 32 to a generator unit 40 which is able to generate electricity from the rotation movement.

[0058] The turbine rotor 32 comprises adaptive blades 42, which adapt to the direction of the water flow. This allows the turbine rotor 32 to be driven by a water flow in any direction along the main housing 16 of the robot 14. In the embodiment shown in figure 9, the adaptive blades 42 are configured to unfold when facing the flow direction of the water along the housing of the robot 14 and to fold when facing away from the flow direction.

[0059] Figure 10 shows a top view of the omnidirectional electric generator 30. The turbine rotor 32 is divided into eight segments, which are divided by a vertical wall 44 whose height decreases from the center of the rotor 32 in radial direction toward the outer circumference of the turbine rotor 32.

[0060] An adaptive blade 42 is connected to each of the walls 44 so that it can pivot between a first position in which the adaptive blade 42 is folded, so that the adaptive blade 42 essentially lies between two neighboring walls 44 and an unfolded position, in which the adaptive blade 42 is unfolded to significantly increase the cross-section of the turbine rotor 32 in the direction of the oncoming water flow. In figure 9, an unfolded adaptive blade 42 is seen on the left side of the turbine rotor 32 and all other adaptive blades 42 are shown folded down. The adaptive blades 42 are preferably designed so that the water flow biases the adaptive blades 42 into the unfolded position on the side of the turbine rotor 32, that rotates along in the direction of the water flow and biases the adaptive blade 42 into the folded position on the side of the turbine rotor 32 that rotates against the direction of the water flow.

[0061] In order to assist the unfolding process of the adaptive blades 42, the turbine rotor 32 may further comprise vanes 46, which are situated in rotational direction 48 ahead of the corresponding adaptive blade 42. The vanes 46 are configured so that the water flow around the main body 16 of the robot 14 may flow into a vane 46, wherein the water flowing into the vane 46 is guided

towards a corresponding adaptive blade 42 in its folded position, e.g. by a channel in the body of the turbine rotor 32. The rotational speed of the turbine is adapted such that the pressure of the water flowing into the corresponding vane 46 then actuates the unfolding of the corresponding (following) adaptive blade 42. The vanes 46 and the corresponding adaptive blades 42 are positioned along the turbine rotor 32 in rotational direction in such a manner that the unfolding of the adaptive blade 42 is actuated at a rotational position, which maximizes the efficiency at which kinetic energy is taken from the water flow.

[0062] The generator unit 40 of figure 9 may also be connected to at least one of the rotating cleaning disks 28 of a cleaning device 20, wherein the generator unit 40 may function as a motor driving the rotating cleaning disks. Couplings and/or reduction gearing may be arranged between the generator unit 40 and the rotating cleaning disk 28 and/or the turbine rotor 32.

[0063] A pump may further be provided in the main housing 16 of the robot 14 which may be driven electrically or mechanically by the turbine rotor 32 and which is able to pump water from the gap between the robot 14 and hull 12 in order to create a suction force which adheres the robot 14 to the hull 12.

[0064] The two turbine rotors 32 of the robot 14 may be connected to a common generator unit 40 or to respective individual generator units 40.

[0065] The robot 14 further comprises a control unit, which is not shown in the figures. The control unit controls at least the maneuvering device 22 of the robot 14. The control device further preferably controls the attachment device 18, in particular if additional attachment units are provided, which can be activated to generate an increased attachment force. The control unit may also control the cleaning device 20, for example by controlling the rotational speed of the rotating cleaning disks 28 or to select different cleaning methods, in particular if a plurality of different types of cleaning devices 20 are provided on the robot 14. The control unit may further control the energy generation device 24. The operation of the robot 14 by the control device may be dependent on the amount of energy generated by the energy generation device 24.

[0066] A battery is provided in the main housing 16 of the robot 14 which can be charged by the excess energy generated by the energy generation device 24. The energy stored in the battery can be used at time when the energy generation device generates little or no energy, e.g. when the marine vessel is in port. The operation of the robot 14 by the control device may further be dependent on the amount of energy stored by the battery.

[0067] The control device may further comprise a number of sensors. In the preferred embodiment the control device includes a sensor for determining the location of the robot 14 on the hull 12. Such a sensor may, for example, detect the direction of the gravitational force and therefore the orientation of the robot 14 and the wall

of the hull 12 of the marine vessel 10.

[0068] The preferred embodiment further comprises a sensor for determining the geographic location of the marine vessel 10. Such a sensor could, for example, receive a GPS signal. It may be necessary for the robot 14 to move to a location at or above the waterline in order for the geographic location sensor to be able to determine the geographic location of the marine vessel.

[0069] Alternatively, it is also possible that the geographic location sensor is located externally of the main robot body and transmits the determined geographic locations locally to the robot 14.

[0070] The preferred embodiment further includes a sensor for determining a degree of bio-fouling on the hull 12. The sensor may, for example, determine whether the bio-fouling is at an initial stage in which only a microbiological biofilm has formed on the hull 12, or whether the bio-fouling is at a higher level in which larger algae and/or animals have attached to the hull 12. Depending on the detected degree of bio-fouling, the control device can control different parameters of the robot, such as the robot maneuvering speed, the path, and/or a cleaning device mode based on the determined degree of bio-fouling.

[0071] The preferred embodiment of the control device further includes a sensor for determining an operating state of the robot. This may, for example, be a degradation level of the cleaning device which enables the robot e.g. to schedule an inspection for replacement of the cleaning device.

[0072] The preferred embodiment of the control device further includes a sensor for determining the direction of a water flow across the main body 16 of the robot 14. This allows the robot for example to orientate itself with regard to the direction of the water flow.

[0073] The control device may also include additional sensors for determination of additional parameters, redundancy or alternative determination methods and may include any combination of the above mentioned sensors.

[0074] The control device preferably controls the robot to move the robot to a safe location on the hull 12, for example at a point half way around the curve where the vertical hull aspect meets the base of the hull when the marine vessel 10 enters a harbor. In this manner an accidental damage to the robot, for example by being crushed between the vessel and a harbor wall or the sea bed, can be prevented. Other safe locations may be defined depending on the shape of the hull 12. The control device may determine that the marine vessel 10 enters a harbor based on the determined geographic location of the marine vessel 10 or via a different method, for example by manual notification of the crew of the marine vessel 10, for example by sending a remote signal to the robot 14. The robot can then move to the safe location based on the determined location of the robot on the hull 12. Alternatively, the robot can follow a predetermined path for such an event.

[0075] The robot 14 may also determine that the marine vessel 10 is entering a harbor when the speed of the marine vessel 10 decreases, which the robot 14 may for example determine based on the determination of the speed and direction of a water flow across the main body of the robot 14 along with the robot's 14 position on the hull 12. Alternatively, sensors may be used to detect vibrations in the hull induced by engines of the vessel.

[0076] The control device further uses the detected geographic location in order to determine whether a cleaning operation is allowed in the corresponding geographic region. If the marine vessel enters a restricted area, then the robot 14 can park itself at or above the water line or at a different location on the hull until the vessel 10 has left the restricted area, at which time the robot 14 can resume the cleaning operation.

[0077] In a preferred embodiment, the robot 14 can perform its functions completely autonomously without direct control from an external operator or device. In particular, it is not necessary for the robot 14 to be tethered to an external device, in particular to be controlled, supplied with energy, or connected to an external cleaning system.

[0078] The robot 14 preferably is only interacting with a service provider which may be independent of the crew, owner or shipping company of the marine vessel 10 and which can schedule deployment, inspection or removal of the robot 14 when the marine vessel is in a suitable port.

[0079] The control device may be programmed when the robot 14 is deployed on a specific marine vessel 10, wherein the configuration may include data of the ship's hull, in particular in order to allow the robot to determine its location on the hull and to determine an effective path of the robot along the hull 12 of the vessel 10 in order to achieve an effective cleaning procedure. The robot path on the hull may be predetermined by a user or may be determined autonomously by the control device of the robot 14.

[0080] The control device may also contain sensors that allow the robot 14 to detect and respond to obstructions or gaps or edges on the hull 12 of the vessel 10. The robot 14 can then control the maneuvering device 22 accordingly to move the robot across or around the obstructions, gaps or edges.

[0081] The robot 14 may also be able to communicate with an external control device, in particular through wireless communication, wherein certain functions, such as the geographical location sensor may be incorporated in the external control device. The external control device may also be used by the crew of the vessel 10 or a remote operator situated remotely from the vessel 10. The external control device may serve for notifying the crew or external operator of the status of the robot, for example if an inspection of the robot or replacement of a worn cleaning device may be necessary. The crew or external operator may also use the external control device to communicate to the robot that the robot should move to a

particular location on the hull 12 of the ship, for example if the ship enters the harbor or for inspection of the robot. It may also be possible to notify the robot 14 of rough weather conditions, which may necessitate a stronger attachment force of the robot on the hull 12 on the vessel 10.

[0082] The control device further may comprise a communication system which allows the robot to communicate with an external service provider/center. The robot may for example report its operating state to the service center which can schedule an inspection of the robot at a suitable time, e.g. the next time the marine vessel is in a suitable port. The communication system may be a satellite communication system or can be a mobile phone system or other wireless communication system which can be used e.g. when the ship is in port and in local range of the wireless communication system. Communication system may include a satellite data link, in particular to be used intermittently when the robot is at or above the waterline; GSM mobile communication system, Bluetooth or Wifi, in particular when in range and the robot is at or above the waterline; and/or acoustic modem, in particular when the marine vessel is in harbor and the marine vessel is stopped

[0083] As a plurality of robots 14 may be connected to each other via the coupling devices 34, the control devices of the respective robots 14 can cooperate in a synergistic manner. It is also possible for a plurality of robots 14 to work together without being coupled via the coupling devices 34, for example by each robot 14 cleaning a predefined portion of the hull.

[0084] Figure 11, figure 12, figure 13, and figure 14 show a second embodiment of a robot 14. The second embodiment of the robot 14 differs from the first embodiment, in that the cleaning device 20 is configured to use the kinetic energy of the water flow across the hull 12 of the marine vessel 10 to rotate the rotating cleaning disks 28. The robot 14 therefore requires less electric energy compared to the first embodiment and therefore may only be fitted with one omnidirectional electric generator 30.

[0085] As can be seen in the top view of the robot 14 in figure 13 and the bottom view of the robot 14 in figure 14, the two rotating cleaning disks 28 are each positioned off-center. The rotating cleaning disk 28 comprises a turbine rotor 50, which is connected to the cleaning disk 28, wherein the turbine rotor 50 comprises adaptive blades 52 which adapt to the direction of the water flow. As can be seen in figures 13 and 14, the turbine rotor 50 of the cleaning disk 28 is positioned so that the side of the turbine rotor, which rotates in the same direction as the water flow, is positioned at a location of the main housing 16 at which it is exposed to the water flow, whereas the section of the turbine rotor 50, which rotates against the direction of the water flow, is located inside the main housing 16 and is therefore shielded from the water flow.

[0086] It is alternatively possible that the turbine rotor 50 comprises fixed blades, which are exposed on one side of the housing and shielded from the water flow on

the other side of the housing. Alternatively, it is also possible to position the rotating cleaning disks 28 centrally in the housing 16 of the robot 14, in which case each of the rotating cleaning disks could be rotated bi-directionally by a water flow on the two respective sides of the robot housing, depending on the arrangement of their adaptive blades 52.

[0087] Figure 15 shows an example of two robots according to the second embodiment which are coupled together via their coupling devices 34, in analogy to the coupled robots of figures 6 to 8 of the first embodiment.

[0088] Figure 16 shows a schematic view of the rotating cleaning disk 28 in a top view in part A of the drawing, a side view in part B of the drawing, and a schematic view of the rotating cleaning disc 28 in an embodiment connected to the omnidirectional electric generator 30 in part C of figure 16.

[0089] The adaptive blades 52 are configured to unfold when facing the flow direction of the water flow and to fold when facing away from the flow direction of the water flowing across the robot 14. The adaptive blades 52 are arranged along the outer circumference of the cleaning disk 28 and can swivel from a closed position, in which they lie against the outer circumference of the rotating cleaning disk 28 into an unfolded position, in which the cross-section of the adaptive blade 52 is increased substantially in order to allow an effective use of the kinetic energy of the water flow. The rotating cleaning disk further comprises a plurality of vanes 54 which are arranged at the top surface of the turbine rotor 50 and which guide water flowing into the vanes 54 towards corresponding adaptive blades 52 in order to actuate the unfolding of the corresponding (following) adaptive blade 52. The corresponding vanes 54 and adaptive blades 52 are situated in rotational direction relative to each other so that the rotational position of the adaptive blade 52 is at an optimal position to maximize the use of the kinetic energy of the water flow.

[0090] The part C of figure 16 shows the turbine rotor 30 coupled to the generator unit 40 via a one-way clutch 56. The generator unit 40 is further coupled to the cleaning disk 28, including the turbine rotor 50 via a planetary reduction gear 58 and a splined shaft 60. This is in particular advantageous if each cleaning disk 28 is coupled to its own turbine rotor 30, similar to first embodiment.

[0091] The turbine rotor 50 connected to the cleaning disk 28 therefore generates mechanical energy from the kinetic energy of the water flow which can be used directly to operate the cleaning disk 28 and in a preferred embodiment can optionally be used to generate electric energy via the generator unit 40.

[0092] The various features of the first and second embodiment may also be combined in different manners, for example it may also be possible to equip the robot 14 of the second embodiment with two omnidirectional electric generators 30.

[0093] Figure 17 shows a third embodiment of a robot 14, which comprises a central segment 62 and a plurality

of arms 64, which extend in radial direction away from the central segment 62. In the embodiment shown in figure 17 the central segment 62 comprises an energy generation device 24 in the form of a centrally arranged omnidirectional electric generator 30 similar to the first embodiment of the invention.

[0094] The central segment 62 is shown in a bottom view in figure 18. The central segment 62 comprises at least two attachment units 66, which are configured to alternately adhere the robot to the hull 12 of the marine vessel 10 at off-center locations of the robot body. It may also be possible to adhere the robot 14 with both attachment units 66 in case a stronger attachment force is required. The attachment units 66 may for example be permanent magnets which are raised or lowered with respect to the hull, electromagnets which are turned on and off, or suction cups to which a vacuum is applied selectively.

[0095] Each of the arms 64 shown in figure 17 comprises of three segments. The two outermost segments 70 and 72 each comprise cleaning devices 20 on their bottom side. The cleaning devices 20 may be mechanical cleaning devices such as brushes or may be other cleaning devices such as UV-light sources, laser or ultrasound sources, or waterjet nozzles or any combination thereof. The number of arms 64 and segments 68, 70, and 72 may vary depending for example on the length of the arms 64 and the shape of the hull 12 of the marine vessel 10 for example to ensure the robot is able to maneuver along the hull 12 efficiently.

[0096] The segments 70 and 72 further each comprise adaptive blades 74, which are configured to move from a first folded position, shown in figure 22 in parts A and C, into an unfolded position shown in figure 22 in part B and part D, in which the cross-section which the corresponding segment 70, 72 offers to the water flow is greatly increased. Further adaptive blades 76 are arranged at the outer tip of the segment 74 as shown top down in figure 21 and edge on in figure 22 b. Part E of figure 22 shows the innermost segment 68.

[0097] The adaptive blades 74 and 76 on each of the outer segments 70 and 72 of the five arms 64 of the robot 14 together form a rotation device which generates a torque acting on the robot body when placed into a water flow across the hull 12 of the marine vessel 10. The rotation device may also only include the adaptive blades 74 situated on the top surface of the arms 64 or may only include the adaptive blades 76 situated at the end of each robot arm 64, in particular depending on the torque needed to rotate the robot 14 efficiently while cleaning the biofouling. This torque is illustrated in figure 17 by the arrows 71. The adaptive blades 74 and 76 may be moved into a closed position when it is not desirable to generate a torque acting on the robot body. As can be seen in figures 20 and 21, the adaptive blades 74 are arranged in a back surface of each of the segments 70 and 74 with respect to the rotation direction of the torque generated by the rotation device. The front surface does not have

adaptive blades and is angled relative to the bottom surface of the segments 70 and 72.

[0098] The maneuvering device 22 of the robot in figure 17 is realized by a cooperation of the torque generating adaptive blades 74 and 76 forming the rotation device and the two attachment units 66 in the central segment 62. If the robot 14 is attached to the hull 12 of the marine vessel 10 at a first off-center location of the robot body, the torque generated by the rotation device rotates the body of the robot around the first off-center location. After rotation of a predetermined angle, for example 180 degrees, the robot attaches the second attachment unit at a second off-center location and releases the first attachment unit so that the robot 14 now rotates around the second off-center location. In this manner the robot can take steps which correspond to the distance between the two off-center locations of the two attachment units 66 and wherein the direction of the steps depend on the angle that the robot rotates between the switches of the attachment units 66. The control device can therefore control movement of the robot 14 by controlling the timing of the switches of the attachment units 66 depending on the angle of rotation of the rotation device.

[0099] The adaptive blades 74 and 76 may be controlled by the control device of the robot 14. In order to prevent the robot 14 from rotating, the adaptive blades 74 and 76 may be controlled to remain locked in their folded position so that the water flow across the robot 14 does not generate a torque that causes the robot 14 to rotate around the first or second off-center location. This may be done when the robot is in a parked position on the hull, e.g. while the marine vessel in a port or for inspection. It may further also be possible to control the degree of unfolding of the adaptive blades 74 and 76 e.g. to control the rotation speed and generated torque.

[0100] The rotation device including the adaptive blades 74 and 76 therefore generates mechanical energy which is used to rotate the robot 14 on the hull 12 of the marine vessel, wherein the rotation of the robot 14 is used both for cleaning the hull 12 and for maneuvering the robot 14 on the hull 12.

[0101] The energy generation device 24 may additionally or alternatively be configured to generate energy from the rotation of the robot body with the arms 64 in relation to the at least two attachment units 66.

[0102] As can be seen in figure 20, the first segment 68 of each arm 64 is a transition segment which raises the central segment 62 relative to the outer segments 70 and 72 of each arm 64. In the present embodiment the two attachment units 66 are preferably permanent magnets which are lowered and raised from the central segment 62 in order to attach and detach the two attachment units.

[0103] Figure 23 shows the central segment 62 of the robot 14 along with the three segments 68, 70, and 72 of one of the arms 64. As can be seen in parts B and C, each of the segments are articulated and can therefore tilt relative to the other segments in order to allow each

robot arm to follow the contour of the hull 12, preferably both concave and convex contours of the hull 12. Each of the segments is preferably biased towards the hull 12 of the marine vessel 10. The shape of the segments 68, 70 and 72 is adapted such that the flow of water pushes the segments towards the hull 12 of the marine vessel 10 by being tapered in both radial and circumferential direction.

[0104] The segments 68, 70, and 72 may also be actuated e.g. by an electric or hydraulic motor to lift up an arm 64, for example to move the arm across an obstacle or an edge on the hull 12.

[0105] Figure 24 shows an example of a cleaning device 20 which consists of a number of cleaning strip segments 78 which each have the ability to be deflected upwards by any impediment on the hull 12 of the vessel 10. Part A of figure 24 shows a view along the length of an arm segment 70 or 72, whereas Part B of figure 24 shows a sideways view which corresponds to the rotation direction. Each individual segment of the cleaning strip 78 can be deflected upwards against the force of a biasing means. In this manner it can be ensured that the robot 14 can move across the hull 12 without damaging it while ensuring that sufficient force is applied to the surface of the hull 12 in order to clean off any bio-fouling.

[0106] The cleaning strip segments 78 may comprise a cutting blade 75 at the front edge of each segment in order to cut any seaweed or plant growth or other stringy marine fouling on the hull 12.

[0107] To protect the cutting blade 75 from damage e.g. from metallic obstructions on the hull 12, a deflector 77 is preferably provided between the cutting blade 75 and the hull 12.

[0108] Figure 25 shows a more detailed front view of a cleaning strip segment 78, figure 26 shows a view of the cleaning strip segment from above and figure 27 shows the cleaning strip segment in a section view along the line XXVII-XXVII indicated in figure 26.

[0109] The cleaning strip segment 78 has a main body 80 which houses a brush-like cleaning unit 82 at its lower side and the cutting blade 75 facing its front edge. The deflector 77 is formed by a number of tapered protrusions of the main body 80 which protrude in forward direction beyond the edge of the cutting blade 75. Between two adjacent protrusions, the cutting blade 75 is exposed so as to be able to efficiently cut any stringy biofouling close to the hull 12. The protrusions of the deflector 77 protect the cutting blade 75 from being damaged e.g. by metallic obstructions of the surface of the hull 12. The spacing of the protrusions of the deflector 77 may be adapted to any such obstructions of the surface of the hull 12.

[0110] The cleaning strip segments 78 as shown in figures 24 to 27 may also be integrated in a rotating cleaning disc 28 of the first and second embodiments.

[0111] A control device for the robot 14 according to the third embodiment can in general contain all the features of the control device of the robot of the first and second embodiment. Given the geometry of the cleaning

devices of the robot 14, according to the third embodiment, it may be advantageous to generate a random path for the cleaning function of the robot, in particular for relatively small hull sizes.

[0112] Different aspects of the different embodiments shown above can also be combined to achieve further advantageous embodiments of the invention.

Claims

1. Anti-fouling robot (14), for cleaning a hull (12) of a marine vessel (10), comprising:

an attachment device (18) configured to adhere the robot (14) to the hull (12) of the marine vessel (10);

a maneuvering device (22) configured to move the robot (14) across the surface of the hull (12) of the marine vessel (10);

a cleaning device (20) configured to remove biofouling from the surface of the hull (12) of the marine vessel (10); and

an energy generation device (24) configured to generate energy for the operation of the robot (14).

2. Anti-fouling robot (14) according to claim 1, wherein the energy generation device (24) comprises at least one electric generator (30) which generates electricity from the relative movement of the marine vessel (10) in the water.

3. Anti-fouling robot (14) according to claim 2, wherein the electric generator (30) is omni-directional.

4. Anti-fouling robot (14) according to claim 2 or 3, wherein the electric generator (30) has a turbine rotor (32), wherein the turbine rotor (32) comprises adaptive blades (42) which adapt to a direction of the water flow, preferably wherein the adaptive blades (42) are configured to unfold when facing the flow direction and to fold when facing away from the flow direction; further preferably wherein the unfolding of the adaptive blades (42) is actuated by water flowing into vanes (46) which are situated in rotational direction ahead of the corresponding adaptive blade (42).

5. Anti-fouling robot (14) according to any of the preceding claims, wherein the attachment device (18) comprises at least one permanent magnet (26) or at least one suction unit.

6. Anti-fouling robot (14) according to any of the preceding claims, wherein the attachment device (18) further comprises additional attachment units which can be activated and deactivated based on a desired attachment force.

7. Anti-fouling robot (14) according to any of the preceding claims, wherein the maneuvering device (22) comprises one or more feet, wheels or continuous track maneuvering devices.

8. Anti-fouling robot (14) according to any of the preceding claims, wherein the maneuvering device (22) comprises

at least two attachment units (66) configured to alternately adhere the robot (14) to the hull (12) of the marine vessel (10) at off-center locations of the robot body and

a rotation device (74, 76) configured to rotate the robot (14) around the off-center locations of the at least two attachment units (66).

9. Anti-fouling robot (14) according to any of the preceding claims, wherein the cleaning device (20) comprises at least one rotating cleaning disc (28).

10. Anti-fouling robot (14) according to claim 9, wherein the rotating cleaning disc (28) comprises a turbine rotor (50) connected to the cleaning disc (28), wherein the turbine rotor (50) comprises adaptive blades (52) configured to adapt to the direction of the water flow, preferably wherein the adaptive blades (52) are configured to unfold when facing the flow direction and to fold when facing away from the flow direction; further preferably wherein the unfolding is actuated by water flowing into vanes (54) which are situated in rotational direction ahead of the corresponding adaptive blade (52).

11. Anti-fouling robot (14) according to any of the preceding claims, wherein the cleaning device (20) comprises a UV light source, a laser or ultrasound source, and/or high pressure jet nozzles.

12. Anti-fouling robot (14) according to any of the preceding claims, wherein the cleaning device (20) comprises radial arms (64) which bias a cleaning unit (78) against the surface of the hull (12) and which move in circumferential direction, wherein the radial arms (64) preferably have a plurality of articulated segments (68, 70, 72)

13. Anti-fouling robot (14) according to any of the preceding claims, wherein the robot (14) further has a control device which has at least one of the following:

a sensor for determining the locations of the robot (14) on the hull (12), wherein the control device preferably controls the robot (14) to move the robot (14) to a safe location on the hull (12) when the marine vessel (10) enters a harbor;

a sensor for determining the geographic location of the marine vessel (10), wherein the control

device preferably controls the robot (14) to stop or start a cleaning operation depending on the geographic location;

a sensor for determining a degree of biofouling on the hull (12), wherein the control device preferably controls the robot maneuvering speed, path and/or a cleaning device mode based on the determined degree of biofouling;

a sensor for determining an operating state of the robot (14), in particular a degradation of the cleaning device (20), wherein the control device preferably controls the robot (14) based on the determined operating state of the robot (14);

a sensor for determining the direction of a water flow.

14. Anti-fouling robot (14) according to any of the preceding claims, wherein the robot (14) has coupling devices (34) configured to couple two or more robots (14) together and wherein two or more coupled robots (14) are configured to be controlled cooperatively.

15. Anti-fouling robot (14) according to any of the preceding claims, wherein the robot (14) is configured to orientate itself on the hull (12) to minimize its cross section in flow direction of the water flow.

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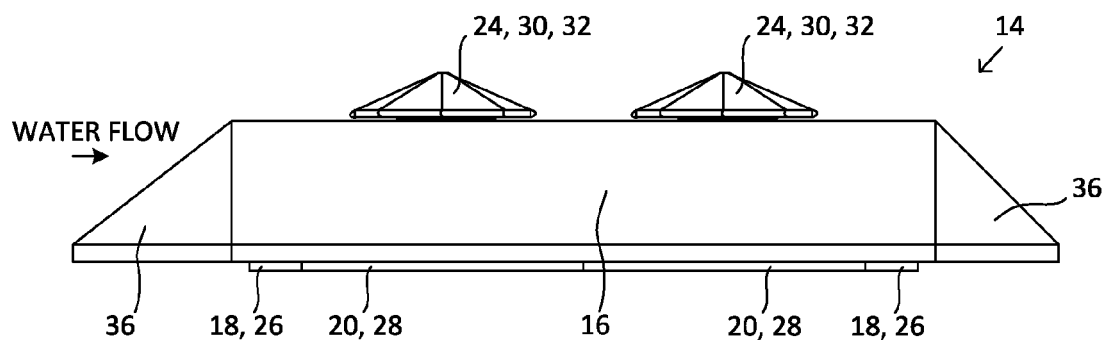
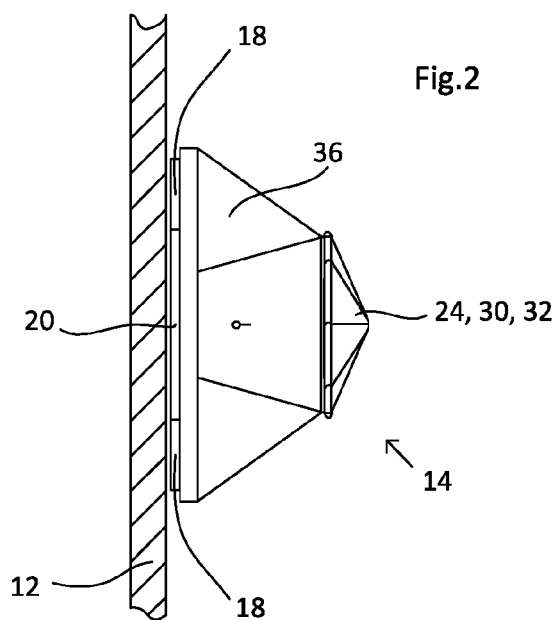
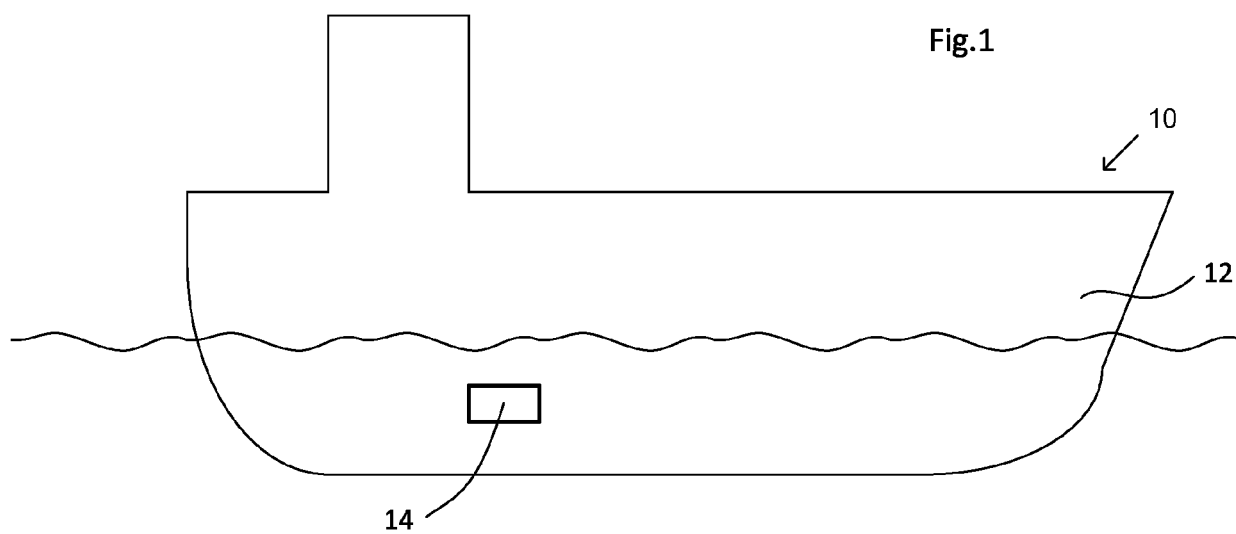
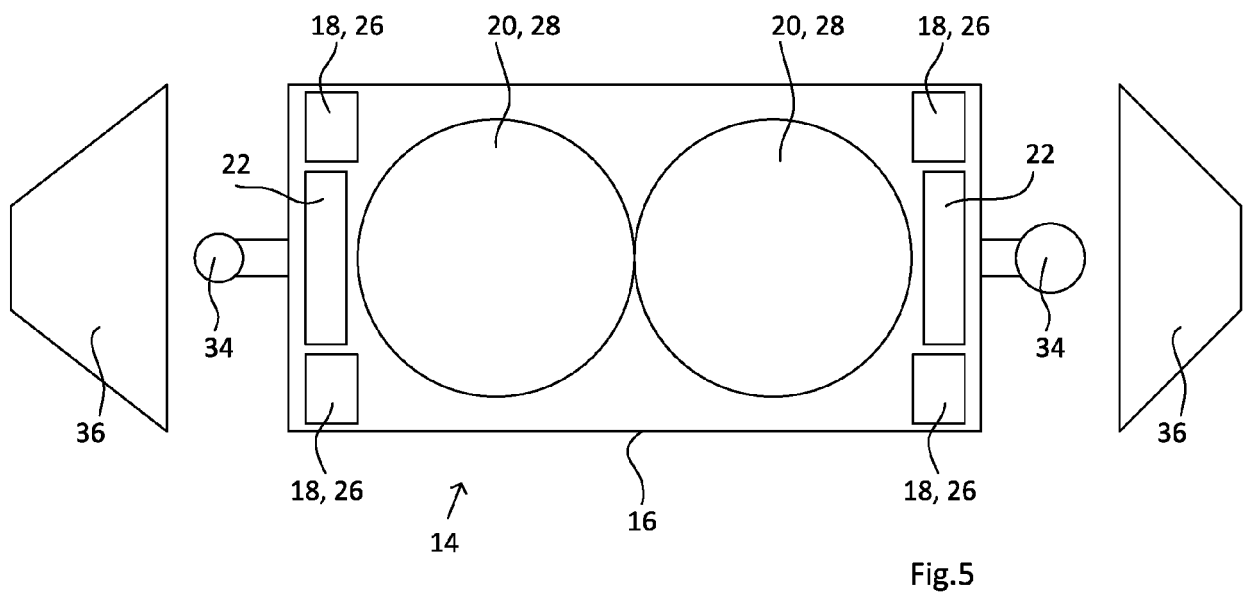
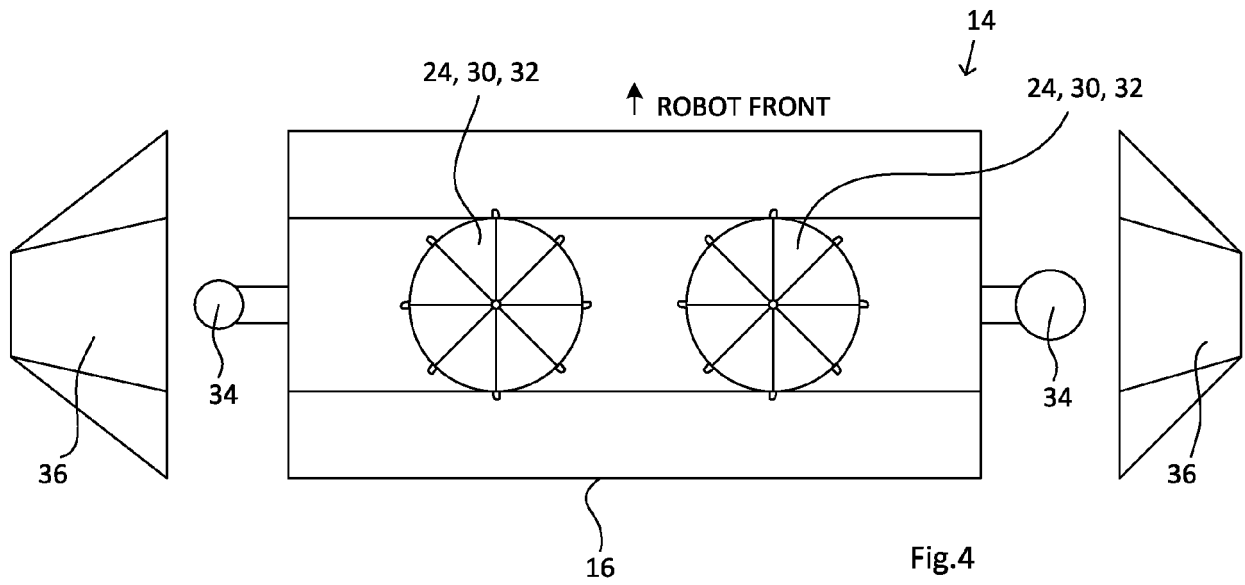
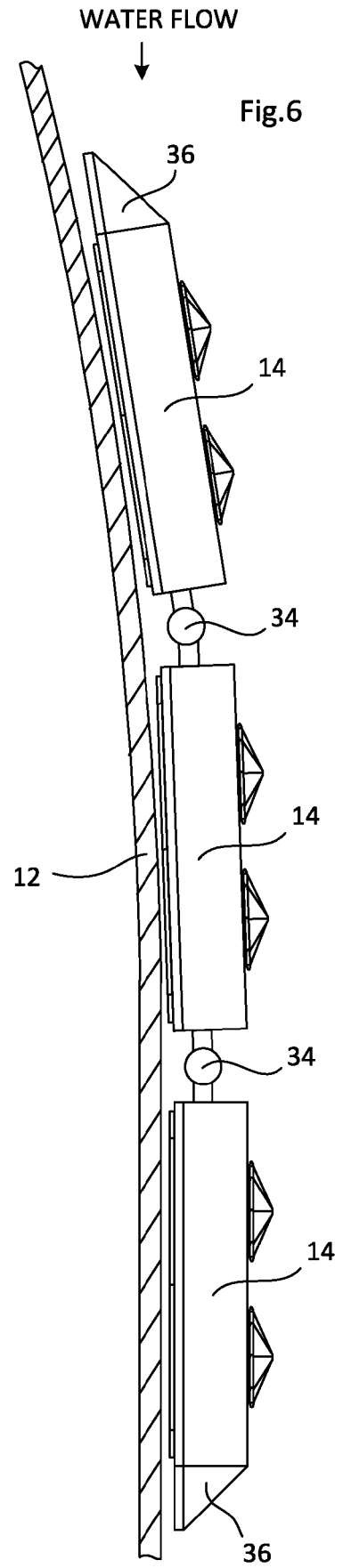
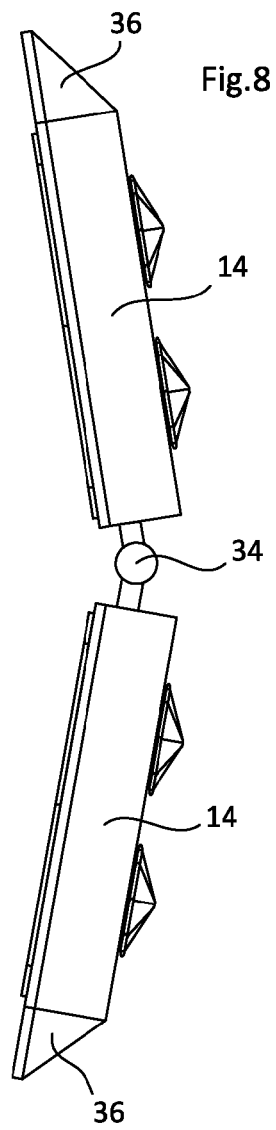
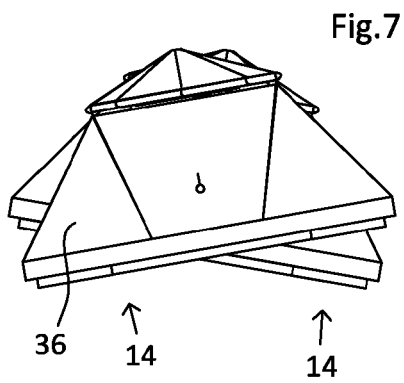


Fig.3





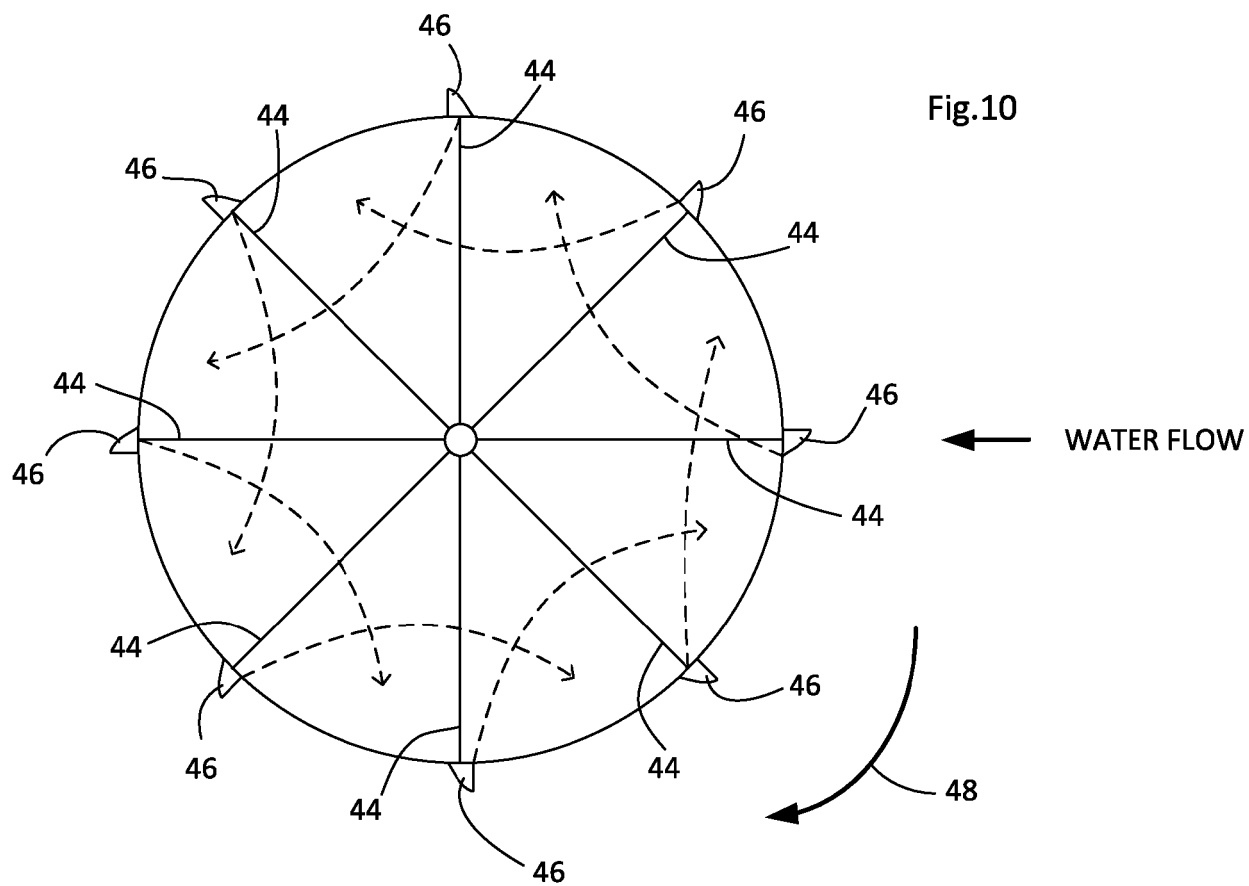
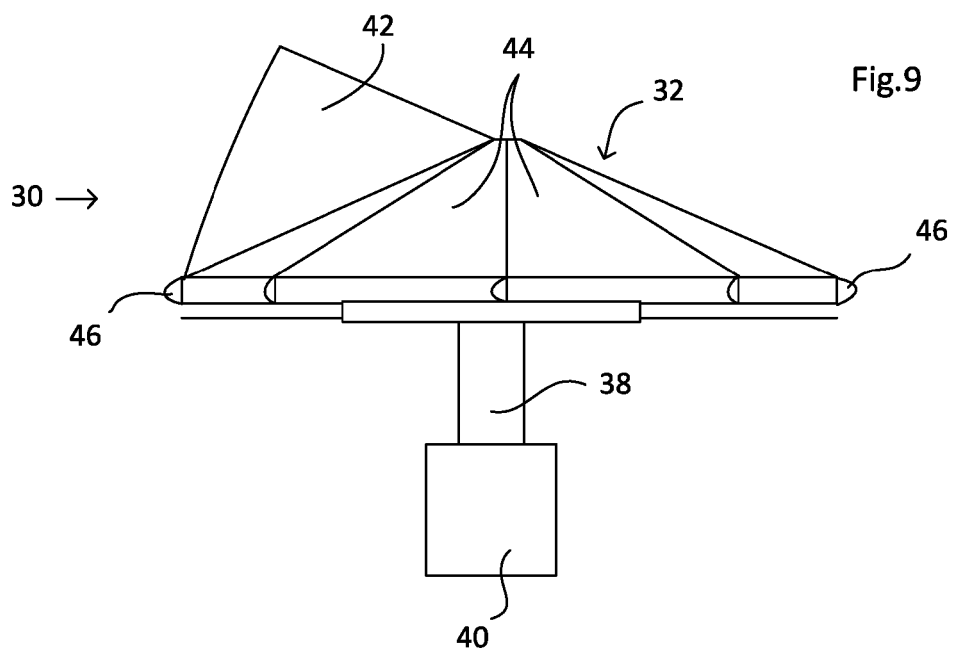


Fig.11

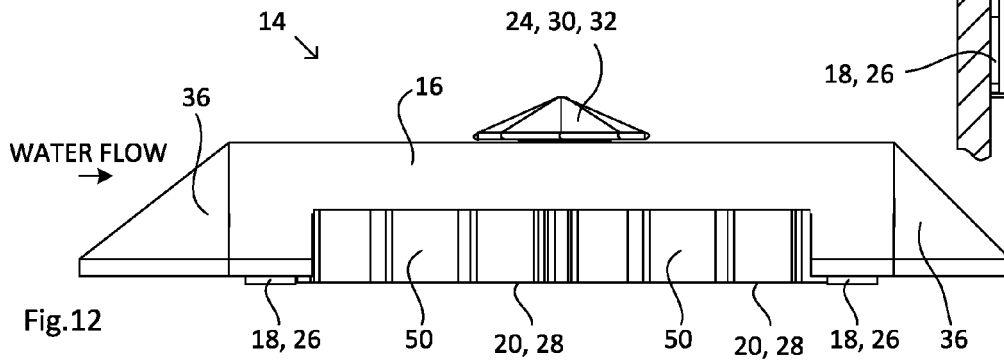
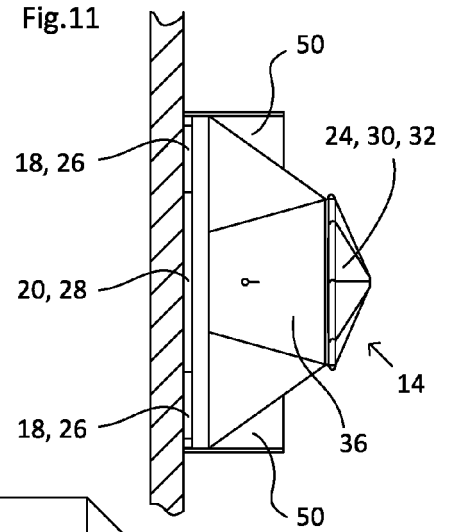


Fig.12

Fig.13

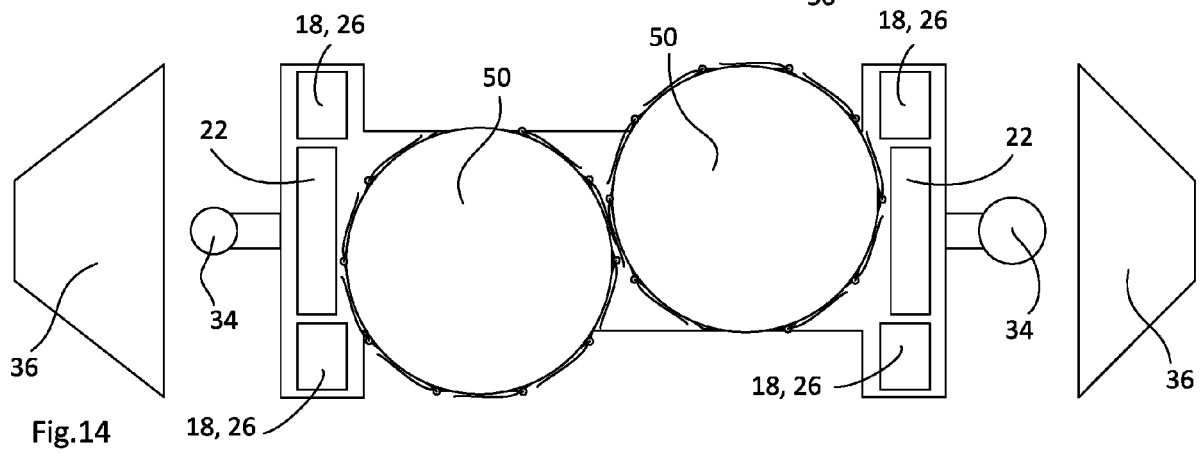
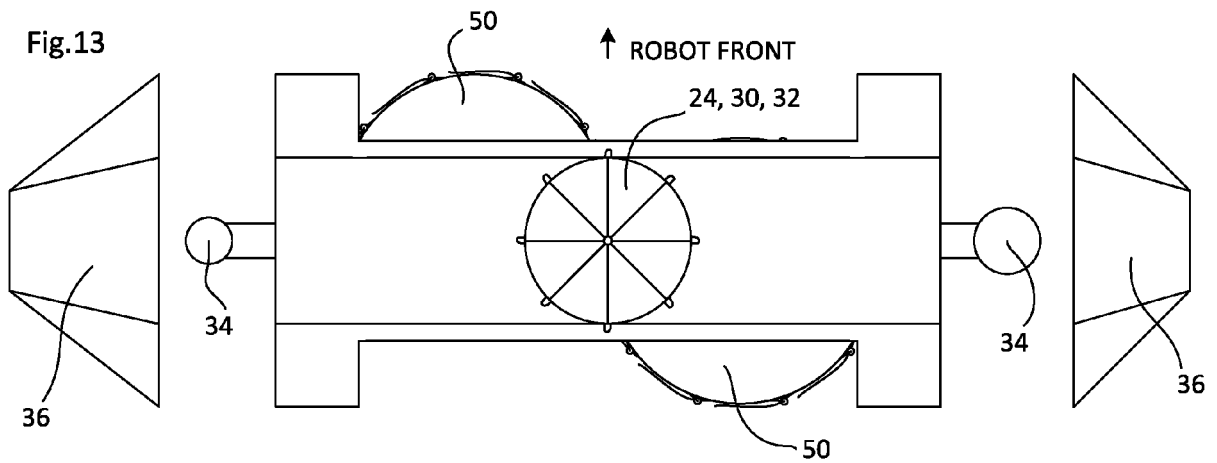


Fig.14

Fig.15

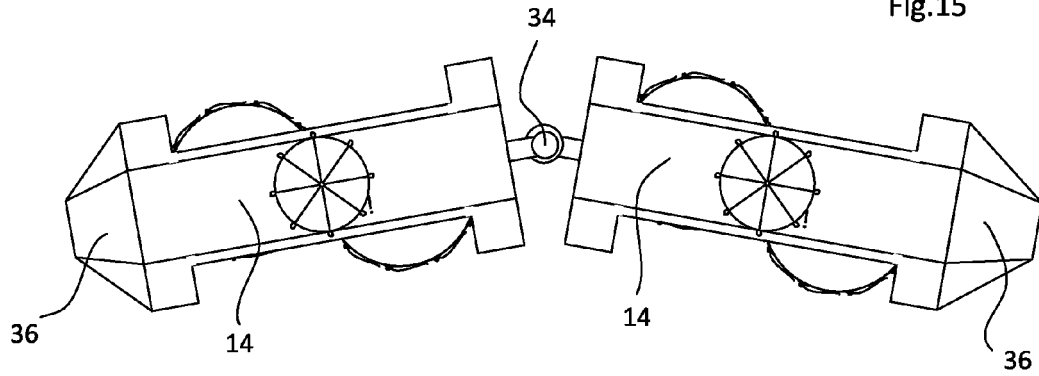
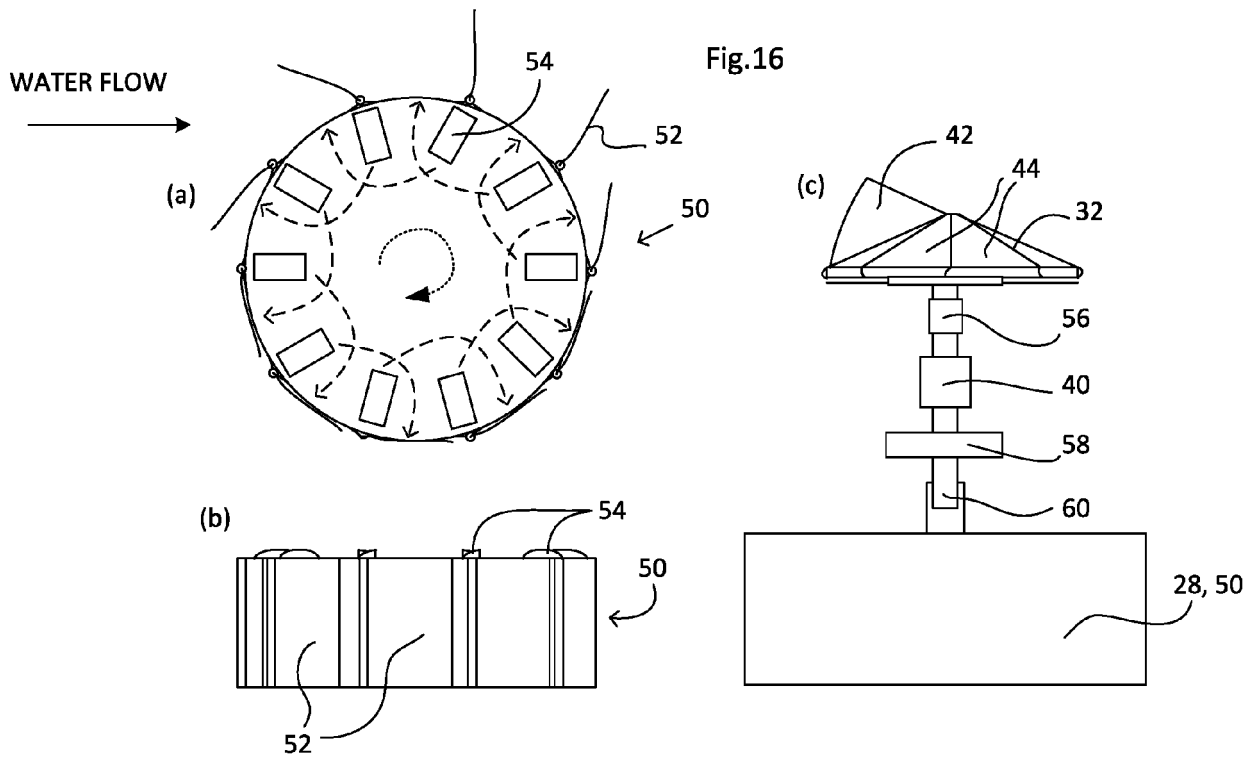
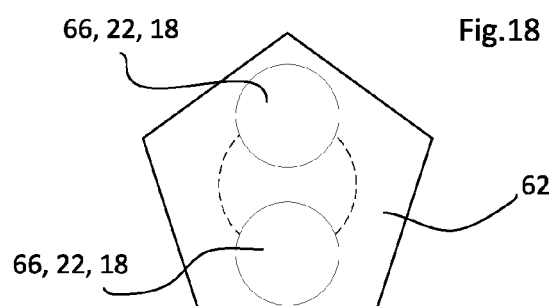
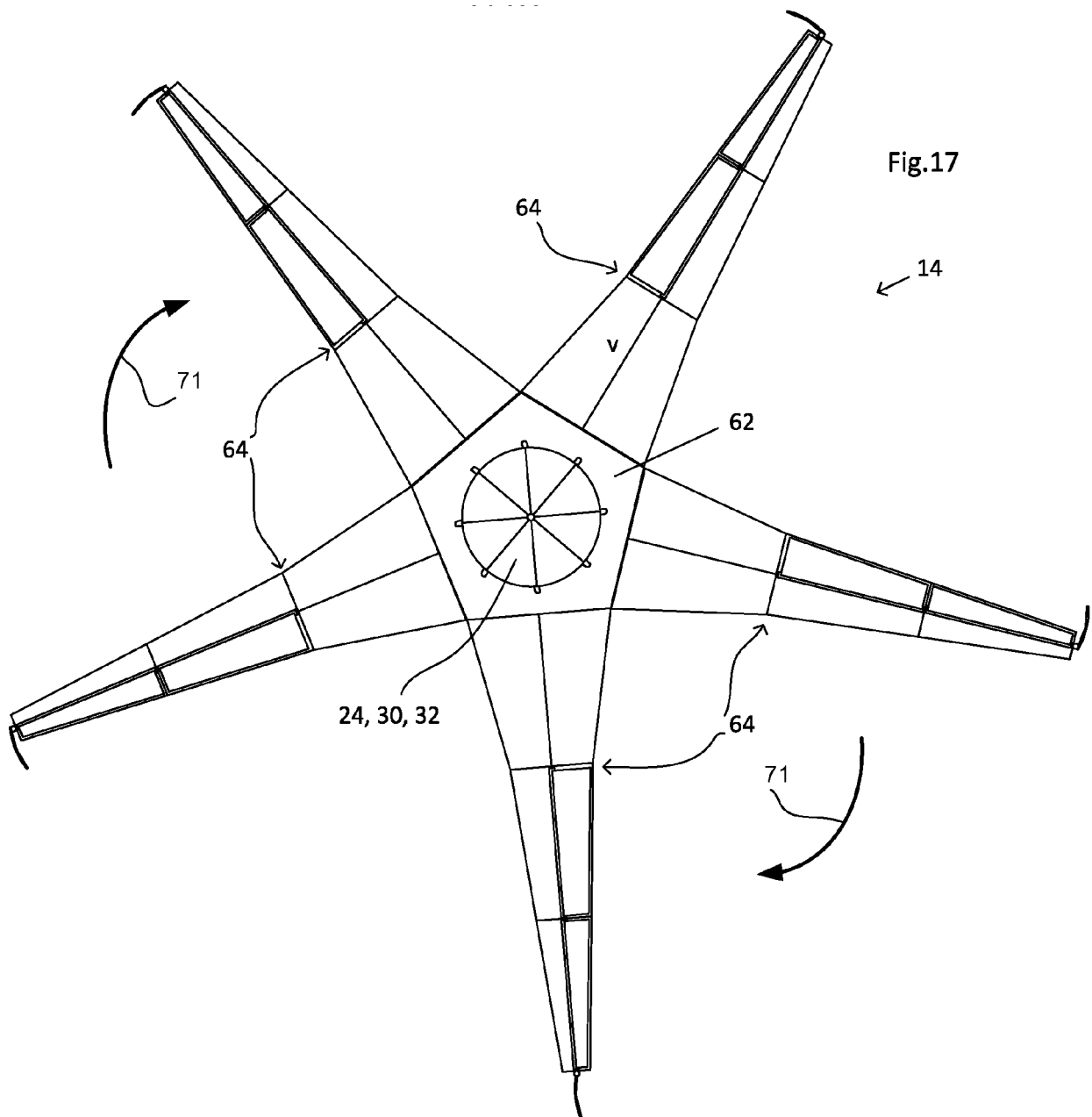


Fig.16





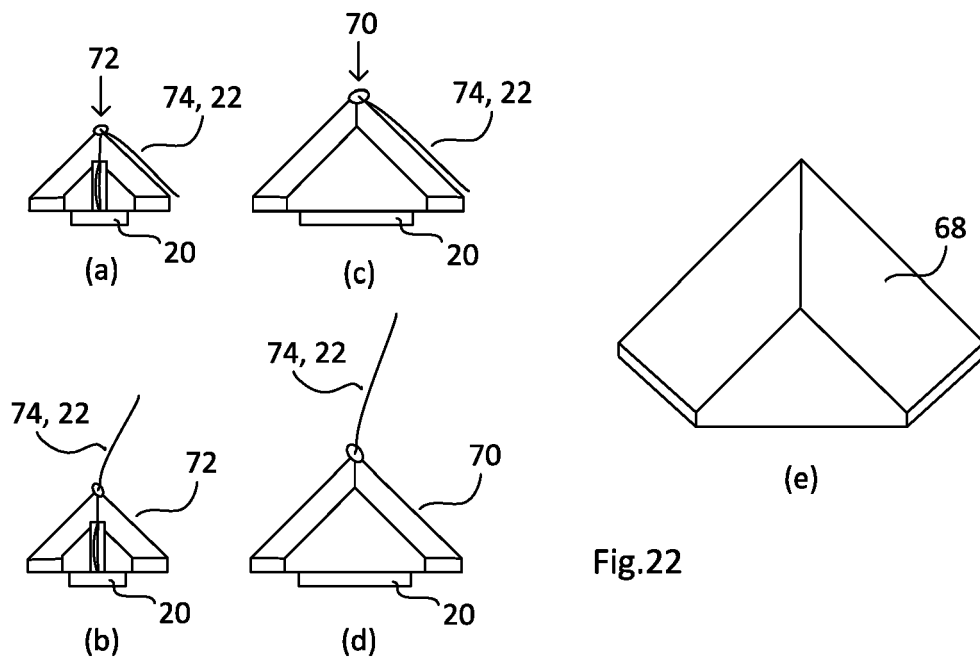
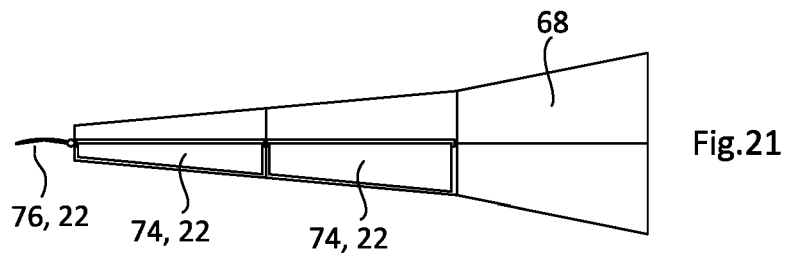
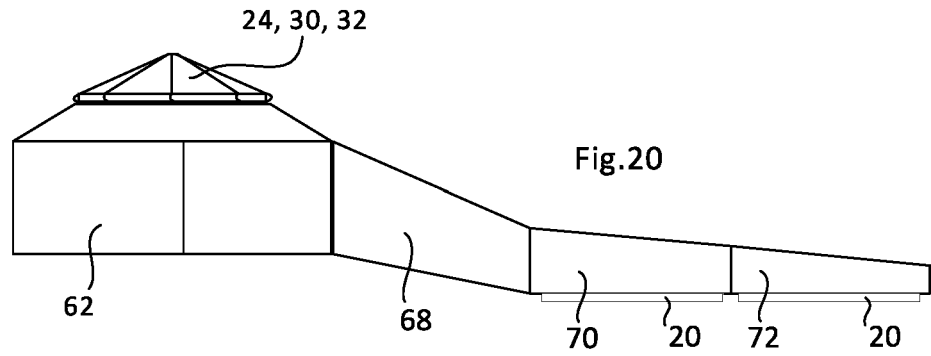
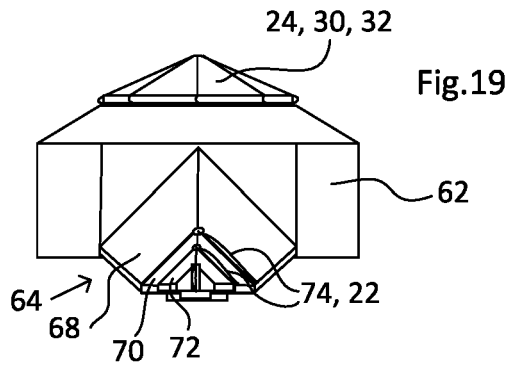


Fig.23

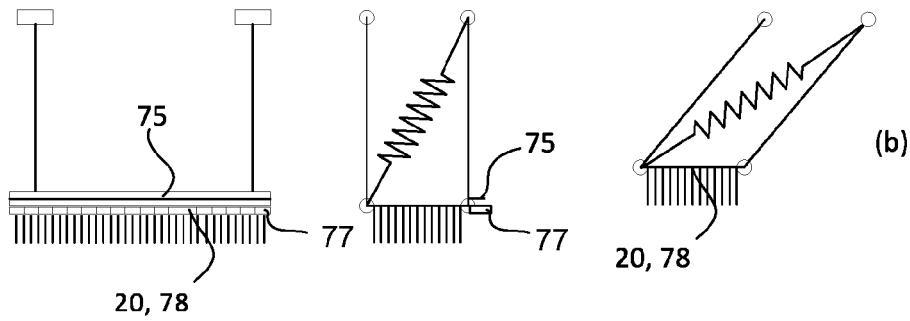
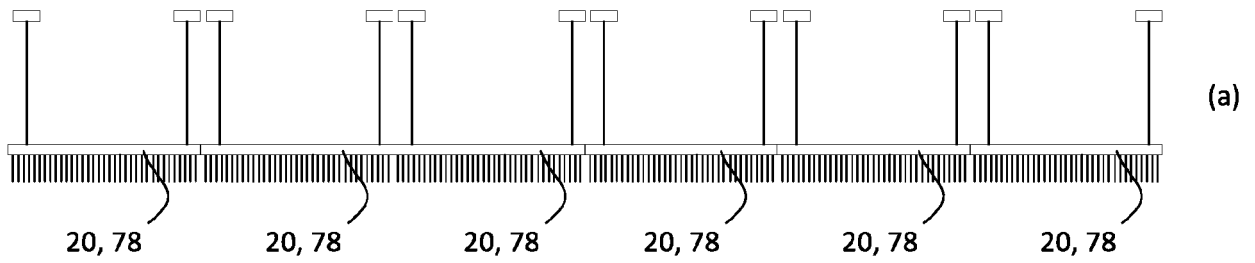
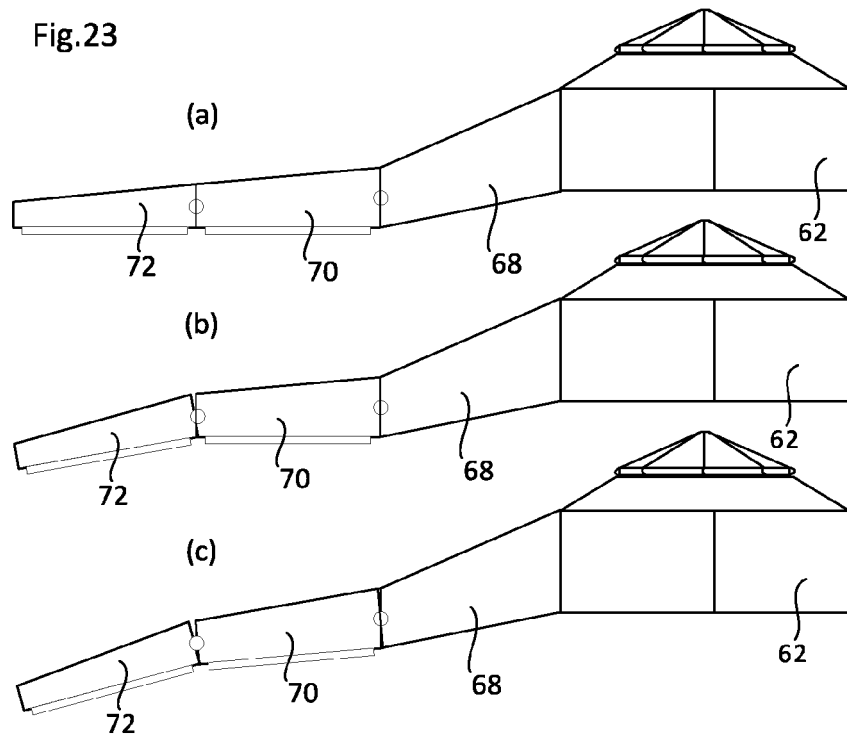


Fig.24

Fig. 25

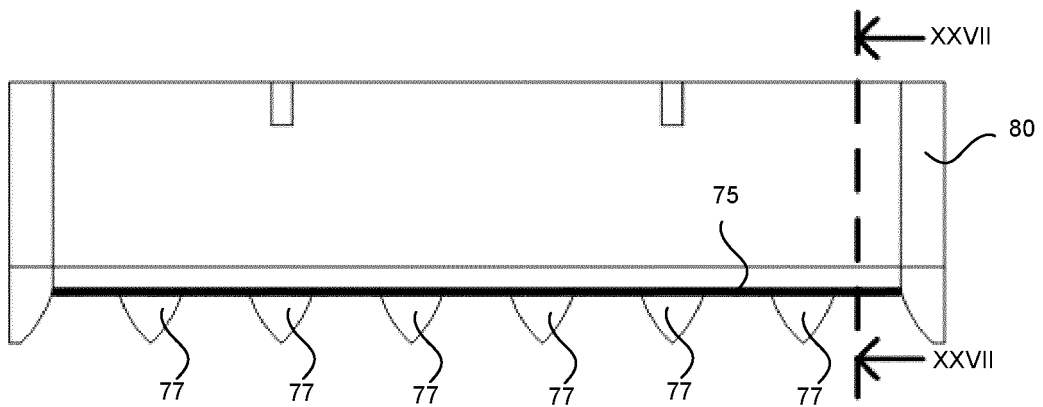
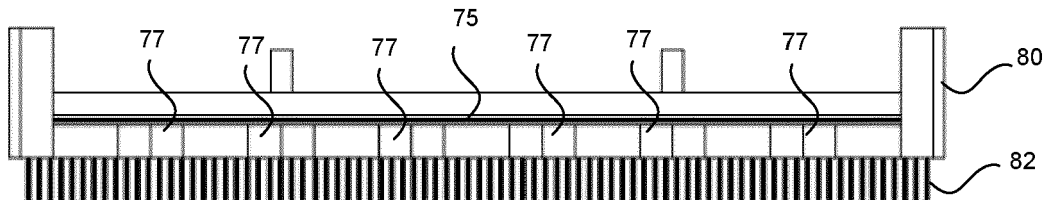


Fig. 26

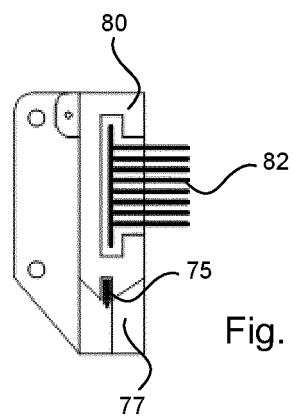


Fig. 27



EUROPEAN SEARCH REPORT

 Application Number
 EP 19 21 7710

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The present search report has been drawn up for all claims			
Place of search The Hague		Date of completion of the search 14 April 2020	Examiner Gardel, Antony
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**ANNEX TO THE EUROPEAN SEARCH REPORT
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5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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